41-0041954

PCT

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [3]: G10K 11/16; H01F 27/33

A1

(11) International Publication Number: WO 81/01479

(43) International Publication Date: 28 May 1981 (28.05.81)

(21) International Application Number: PCT/GB80/00194

(22) International Filing Date: 10 November 1980 (10.11.80)

(31) Priority Application Number: 7939005

(32) Priority Date: 10 November 1979 (10.11.79)

(33) Priority Country: GB

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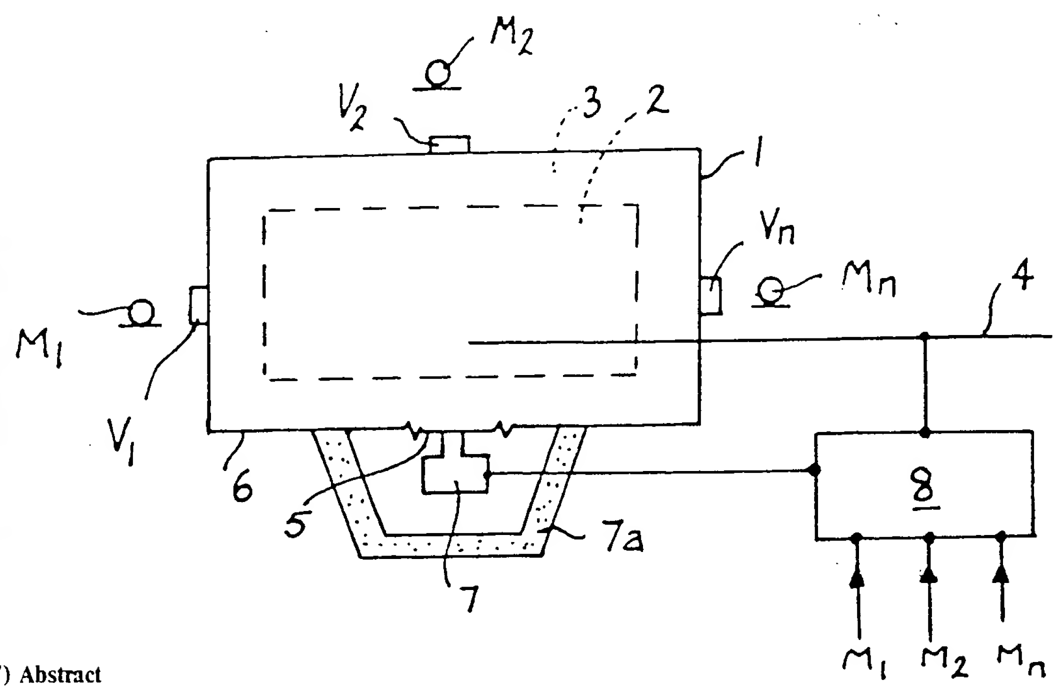
(81) Designated States: AT (European patent), AU, CH (European patent), DE (European patent), FR (European patent), GB (European patent), LU (European patent), NL (European patent), NO, SE (European patent), US.

Published

With international search report

(54) Title: THE CANCELLING OF VIBRATIONS TRANSMITTED THROUGH A FLUID IN A CONTAINING VESSEL



(57) Abstract

Method of and apparatus for reducing the vibration (e.g. noise) transmitted into the environment of a fluid-containing vessel by a vibration source within the vessel. The invention relies on an "active" attenuation method in which a specially tailored cancelling vibration is applied to the fluid in the vessel, whereby at least partial cancellation of the vibration from the source occurs within the fluid. The invention has particular application to reducing the environmental noise nuisance caused by the core (2) in an oil-filled transformer tank (1), a vibrator (7) being energised by a waveform generator (8) and injecting the cancelling vibration into the oil (3) via a diaphragm (5). The output from vibration sensors (M_1.....M_n) can be used to control the generator (8). The invention can also be applied to pumps and fluid filled pipes.

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The cancelling of vibrations transmitted through a fluid in a containing vessel

Technical Field

This invention relates to a method of, and apparatus for reducing the vibration (e.g. noise) transmitted into the environment of a fluid-containing vessel by a vibration source within the vessel. The invention has particular application to reducing the environmental noise nuisance caused, for example, by an oil-filled transformer tank, a fluid compressor or pump, a pipeline conveying a flowing fluid or the cylinder block of an engine.

Background Art

It is well known that vibrations induced by the core of a transformer are transmitted through the oil surrounding the core to the walls of the oil-containing tank and thence to the atmosphere. It is frequently economically necessary to site a transformer close to private dwellings and the constant hum made by such transformers constitutes a form of environmental pollution which is objectionable to those forced to live within range of the noise.

To reduce the pollution it is known to enclose the transformer in a building with dense walls and roof. However, such an acoustic shield is expensive to erect and maintain and enclosing the transformer within a building exacerbates the problem of removing the waste heat from the transformer.

It is also known that unacceptably high levels of noise and vibration emanate from fluid compressors, pumps and pipelines conveying flowing fluid and the irritation caused by the noise has either to be tolerated or the noise damped with various types of passive silencers.

liquid-filled spaces in the block (e.g. spaces containing coolant). There has so far been no acceptable proposal for eliminating this noise source.

There is thus a need for a simple means of attenuating vibrations arising in a range of different fluid-filled vessels.

It has been proposed to cancel noise emanating from a variety of different sources by an active attenuation method which involves generating a specially tailored 'anti-noise' signal which will react with the noise and, to at least some extent, to null it. Heretofore these active attenuation methods have operated in the atmosphere.

Examples of prior-art active sound attenuating methods and apparatus can be taken from the specifications of U.K. Patents 1555760 and 1577322.

Disclosure of the Invention

The present invention relates, in part, to a method of reducing the vibration transmitted into the environment of a fluid-containing vessel by a primary vibration source within the vessel which comprises generating a cancelling vibration which will at least partly null the transmitted vibration. According to one aspect of the invention, such a method is characterised in that the cancelling vibration is applied to the fluid in the vessel whereby the at least partial cancellation occurs within the vessel.

The method of the invention finds application mainly in liquid-filled vessels but its extension to gas-filled vesseks is not ruled out and hence the term "fluid" as used herein, should be taken to cover both liquid and gas.

Suitably the cancelling vibration is generated by at

into the fluid in the vessel. Where the source of primary vibration in the vessel is a distributed source (e.g. in the case of a large transformer core) it will normally be desirable to use a plurality of cancelling vibration sources, placed at appropriate locations around the distributed source.

One suitable form of transducer for generating the cancelling vibration in a liquid is a piston reciprocating in a tube dipping into the liquid in the vessel. This piston can have the same cross-sectional area as the immersed tube, or it could be smaller or larger than the cross-sectional area of the tube. Optionally, the wall of such a tube is made compressible, so that the cancelling vibrations spread out from the open end of the tube with negligible vibration being transmitted through the wall of the tube.

Conventional electrodynamic vibrators can be used as the source of the secondary vibrations in a liquid-filled vessel and these are available with power outputs ranging from a few watts to a few kilowatts.

A hydraulic servo actuator, e.g. controlled by a piezo-electric generator, can also be used. In a gas-filled vessel one or more conventional loudspeaker systems can be used.

The secondary vibration source could be located outside the vessel (e.g. housed in a sound-proof enclosure) and could transmit the secondary vibrations to the contained fluid through a resilient part of a wall of the vessel (e.g. through a diaphragm mounted in the wall).

The driver for the secondary vibration source would desirably be influenced by one or more microphones located adjacent to the vessel, or one or more vibration sensors mounted on the wall of the vessel, so that a sensing of the effectiveness of a contemporary nulling operation can be assessed and improved on by adju...

nature of the vibrations from the source in the vessel changes with time, and may be desirable even in cases where the primary source has a sensibly constant output, since providing an adaptive capacity, reduces the demands on the accuracy of the initial installation of the vibration-cancelling equipment.

Where the method of the invention is applied to an oil-filled transformer, reducing the noise nuisance by operating within the transformer tank has the significant advantage that the wavelength of the primary vibrations from the core of the transformer is some five times greater than the resulting noise emitted into the air from the tank walls. This in turn means that the effective size of the core (which acts as a large distributed source) is reduced, and the spacing-apart of the sources of secondary vibration within the tank, can be correspondingly increased. A typical spacing for the secondary vibration sources would be between one third and one sixth of the wavelength of the primary vibration, so that for a 100 Hz vibration in oil a spacing in oil of between 5 metres and 2.5 metres is acceptable.

In the case of a transformer operating at 50 Hz, it has been found that the major noise nuisance in the environment arises from the even harmonics of the a.c. supply and the sources of secondary vibration are suitably arranged to generate a complex vibration made up of components at 100 Hz, 200 Hz and optionally also 300 Hz. The higher even harmonics are not normally required for acceptable noise nuisance reduction. Since these harmonics are sensibly pure sine waves, the driver(s) for the secondary source(s) need only be controlled with regard to amplitude and phase - thus considerably simplifying the electronics of the control system for the driver(s).

Where the primary vibration is broad band (e.g. as would arise with a compressor, a pump, a fluid line or an engine

a satisfactory secondary vibration may operate in the manner described in the aforementioned U.K. patent specifications, in which the driving waveform is analysed in a discrete number (e.g. 32 or 64) of adjacent time slots, the signal amplitude in each time slot being sequentially adjusted on a trial-and-error basis to reduce the signal received from one or more residual noise sensing microphones disposed around the vessel containing the primary source.

The invention also extends to apparatus for reducing the vibration transmitted into the environment of a fluid-filled vessel by a primary vibration source within the vessel which apparatus comprises means to generate a cancelling vibration which will at least partly null the transmitted vibration, characterised in that the cancelling vibration generating means is adapted to be disposed on or within the vessel to apply the cancelling vibration directly or indirectly to the fluid within the vessel.

A still further feature of the invention relates to a transformer having a core within an oil-filled tank which is characterised in that at least one vibrator is mounted on or in the tank to induce secondary vibrations in the oil which will at least partly null the primary vibration emanating from the core.

Brief Description of the Drawings

The invention will now be further described, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a purely schematic view of a transformer adapted to reduce noise pollution in accordance with the method of the invention,

Figure 2 is a graph indicating a typical frequency spectrum of noise from a large power transformer,

Figure 3 is a schematic sectional plan from above of a transformer tank adapted to reduce its ambient hum in accordance with the method of the invention,

Figure 4 is a schematic sectional side elevation of the tank of Figure 3 on the line IV-IV thereof,

Figures 5*a* and 5*b* are schematic representations of alternative forms of secondary vibration source for the embodiment of Figures 3 and 4,

Figure 6 is a block diagram of a circuit usable to drive the secondary vibration sources of Figures 1, 3, 4, 5*a* or 5*b*, and

Figure 7 is a schematic representation of how the method of the invention can be applied to vibrations radiating from a fluid pipeline.

Best Mode of Carrying out the Invention

Figure 1 shows a transformer tank 1, containing a core 2 surrounded by oil 3 and fed from an a.c. power line 4. A diaphragm 5 forms part of one wall 6 of the tank 1 and a vibrator 7 is mounted on the diaphragm 5 to generate secondary vibrations within the oil 3 which null the primary vibrations transmitted to the oil 3 from the core 2. The vibrator 7 is driven by a driver 8 which receives input signals both from the line 4 and from a series of noise-sensing microphones M_1, M_2.....M_n disposed in the atmosphere around the tank 1. The driver 8 can be of the kind shown in Figure 6

Figure 2 shows a typical frequency spectrum of the hum from a large primary step-down power transformer (e.g. of several hundred kilowatts rating) operating on a line frequency of f = 50 Hz. It is expected that a similar spectrum would be obtained if the fundamental frequency were f = 60 Hz, the peaks of energy then appearing at 120 (2f)

To null the hum represented by Figure 2, the vibrator 7 can be fed with a specially tailored waveform generated from sinusoidal waves having frequencies at the three even harmonics 2f, 4f and 6f, the amplitudes and phases of the harmonic components being selected to give the lowest possible summed output from the microphones $M_1 \ldots\ldots M_n$.

In a simple arrangement, only the part of the block diagram shown in the dashed-line box 10 in Figure 6 is required to produce a satisfactory nulling secondary vibration waveform. Referring to Figure 6, an a.c. signal taken from the line 4 is fed into a harmonic generator 11 (e.g. a half-wave rectifier) and the output is fed to pass filters 12a, 12b and 12c tuned respectively to pass the 2f, the 4f and the 6f harmonic. The output from the pass filter 12a is fed into a variable phase shifter 13a and then into a variable amplitude control 14a. Similar phase shifters 13b, 13c and amplitude controls 14b, 14c are used for the 4f and 6f harmonics and the outputs from the three amplitude controls 14a, 14b and 14c are fed to a summer 15 and thence to a power amplifier 16 of variable gain. The output from the power amplifier 16 leads to the vibrator 7.

By manually adjusting the variable components 13a...13c, 14a...14c and 16 when the transformer has been installed in its working location, while watching a power meter fed from the microphones $M_1 \ldots M_n$, the hum can readily be reduced to an acceptable level dispensing with the need for an acoustic shield around the transformer tank 1. Periodic checking of the setting of the variable components 13a....13c, 14a....14c and/or 16 can be made at intervals during the working life of the transformer, the microphones being removed between checks if desired.

Vibration sensors V_1, $V_2 \ldots V_n$ can be used on the walls of the tank 1 in place of the microphones $M_1 \ldots M_n$ for the residual power sensing operation, inside or outside the tank.

A more sophisticated control arrangement is obtained by using the full block diagram shown in Figure 6 which utilises a microprocessor 17 to effect the adjustment of the components 13a....13c, 14a....14c and 16 automatically on a coninuous assessment of the residual noise transmitted by the tank 1 as received by the microphones $M_1 \ldots . M_n$. The output from each microphone (only M_1 is shown in Figure 6 for convenience) is fed to a pre-amplifier 18 and then to a squarer 19 to give an output whose voltage is related to acoustic power received by the microphone. The power-related output from the squarer 19 is fed to a voltage to frequency converter 20 and then to a counter section 21 of the microprocessor 17. It will be appreciated that the output of the counter 21 in any unit time will be the integral over that unit time interval of the power received by the microphones.

The output ports 22 of the microprocessor 17 are connected to a respective digital control unit of each of the adjustable components 13a....13c, 14a...14c and 16 in the box 10. Only the control unit (13d, 14d) for the units 13c and 14c has been shown in the drawing to avoid complication.

The sequencing operation conducted by the microprocessor can be to take first the 6f harmonic and make incremental adjustments, via unit 13d, of the setting of unit 13c until the counter 21 shows its lowest reading in the unit time interval. This adjustment is then repeated with each of the adjustable components cyclically time after time, each adjustment being retained if it improved the nulling, but not otherwise. By adapting the driving waveform of the vibrator 7 in this way, the system described can not only set itself up initially, but can compensate for changes occurring in the primary vibrations generated by the core during use.

Since the vibrator 7 is in the atmosphere and is a noise source *per se*, it is surrounded by a sound attenuating enclosure 7a. If the wall 6 is flexible enough, the diaphragm 5 can be dispensed with.

In practice, more than one vibrator 7 would be required in a large transformer tank and these can be separately driven each from its own waveform generator (e.g. the components in the box 10 in Figure 6) or some or all from a common generator. Figures 3 and 4 show a plurality of vibrators actually located inside the tank of a transformer and spaced apart by a distance (e.g. l in Figure 3) which is between one sixth and one third of the wavelength of the predominant harmonic in oil. Primed numerals have been used in these Figures to represent corresponding items to those designated without primes in Figure 1.

The vibrators 7' shown in Figures 3 and 4 employ a piston 30 reciprocating in a resiliently walled tube 31 (e.g. a rubber tube or a hollow metal tube as shown in Figures 5a and 5b). The height "h" of the lower end of each tube 31 and its position relative to the core 2' can be adjusted to optimise the nulling effect in the oil 3' and virtually eliminate any vibration of the walls of the tank 1'.

The vibrators 7' can be lowered into the tank from above into holes cut in the top of the tank, making it a relatively easy matter to modify an existing on-site transformer.

Figures 5a and 5b show alternative arrangements for the pistons 30 which may be required in some cases.

As an alternative to using a driving waveform for the vibrators 7, 7' derived from the harmonics of the line frequency, a waveform can be derived from a special generator using the method described in the abovementioned U.K. patent specifications, the necessary clocking frequency for the real time sampling of the generator waveform to adapt it to the primary vibration being obtained from a higher frequency signal synchronised to the line frequency.

Figure 7 shows a pump 40 moving fluid along a pipe 41

vibrator 43 can be of any convenient design and will be driven reciprocally to generate a secondary vibration in the flowing fluid which will there null the primary vibrations coming from the pump. Since these primary vibrations will not have the simple harmonic constituents appearing in a transformer tank, but will be more broad band - it will be necessary to power the driver 44 with a specially-generated waveform (e.g. generated as described in the aforementioned U.K. patent specifications) and to tailor that waveform to produce a minimum output from a vibration sensor 45. A similar technique to that required for the pipe 41 can be used to reduce the fluid-transmitted vibrations in an engine block, a hydrophone or the like being used within the liquid channels to optimise the nulling effect.

CLAIMS

1. A method of reducing the vibration transmitted into the environment of a fluid-containing vessel (1) by a primary vibration source (2) within the vessel which comprises generating a cancelling vibration which will at least partly null the transmitted vibration, characterised in that the cancelling vibration is applied to the fluid (3) in the vessel (1) whereby the at least partial canellation occurs within the vessel (1).

2. A method as claimed in claim 1, characterised in that at least one microphone ($M_1 \ldots M_n$) is located outside the vessel (1) or at least one vibration sensor ($V_1 \ldots V_n$) is disposed on or in the vessel (1) and the cancelling vibration is modified on the basis of the output from the said microphone or vibration sensor to improve the effectiveness of the nulling operation.

3. A method as claimed in claim 1 or claim 2, characterised in that the source (2) of the primary vibration is a transformer core fed from an a.c. line (4) and a driving waveform used to power the source (7) of the cancelling vibration is derived from a mixture of harmonics of the frequency of the a.c. supply, each harmonic component of the driving waveform being controlled with regard to amplitude and phase.

4. A method as claimed in claim 3, characterised in that the harmonics are derived from the a.c. line (4) by filtering the output of a harmonic generator (11) fed with power at the fundamental frequency of the a.c. supply, the amplitude and phase of each harmonic signal being automatically adjusted by a microprocessor (17) to optimise the nulling operation.

5. Apparatus for reducing the vibration transmitted into the environment of a fluid-filled vessel (1) by a primary vibration source (2) within the vessel which apparatus comprises means to generate a cancelling vibration which will at least partly null the transmitted vibration

in that the cancelling vibration generating means (7) is adapted to be disposed on or within the vessel to apply the cancelling vibration directly or indirectly to the fluid (3) within the vessel (1).

6. Apparatus as claimed in claim 5, characterised in that the cancelling vibration generating means (7) comprises a movable part (5, 30) in contact with the fluid (3) in the vessel (1) said movable part being vibrated by an electrical actuator driven by a waveform generator (8, 10).

7. Apparatus as claimed in claim 6, characterised in that at least one vibration-detecting device (M_1, V_1) is disposed outside the vessel to sense the residual vibration emitted from the vessel, the output from the waveform generator (8, 10) being adapted to improve the contempoary nulling operation on the basis of the residual power sensed by the at least one vibration-detecting device (M_1, V_1).

8. Apparatus as claimed in claim 6 or claim 7, characterised in that the movable part of each cancelling vibration generating means (7') is a piston (30) reciprocating in a tube (31).

9. A transformer having a core (2) within an oil-filled tank (1) characterised in that at least one vibrator is mounted on or in the tank to induce secondary vibrations in the oil (3) which will at least partly null the primary vibration emanating from the core (2).

10. A transformer as claimed in claim 9, characterised in that there are a plurality of vibrators (7') disposed to induce secondary vibrations in the oil (3') at spaced-apart locations around the core (2'), and there are a plurality of vibration-sensing devices (M_1, V_1) disposed outside the tank (1'), the output of the vibration-sensing devices (M_1, V_1) being used to control the output of a waveform generator (10) used to actuate the vibrators (7').

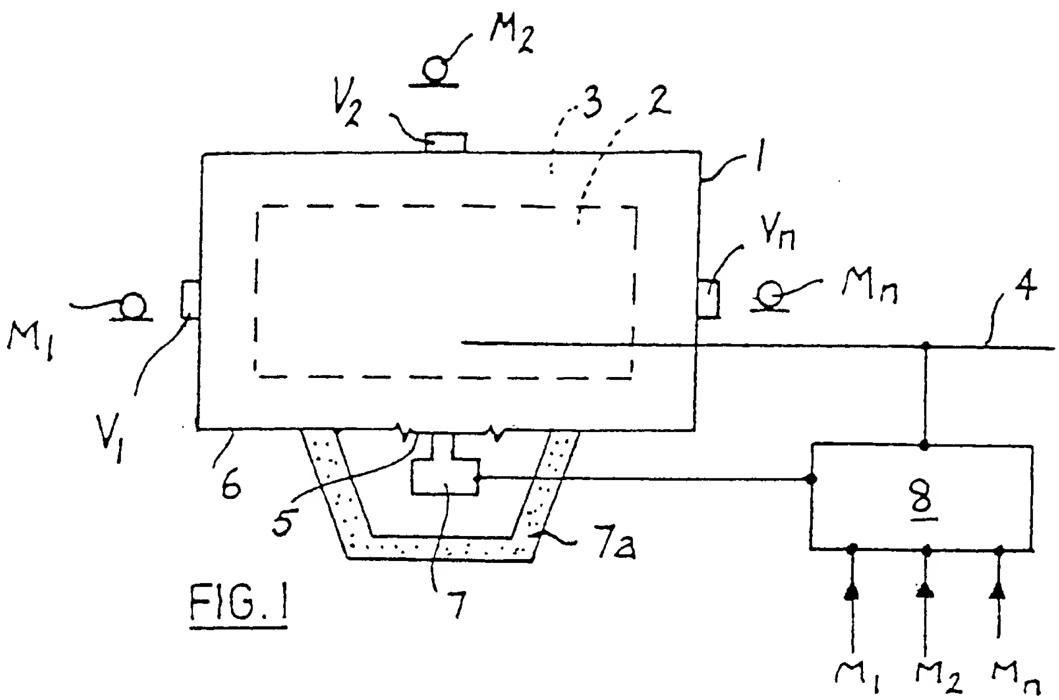

FIG. 1

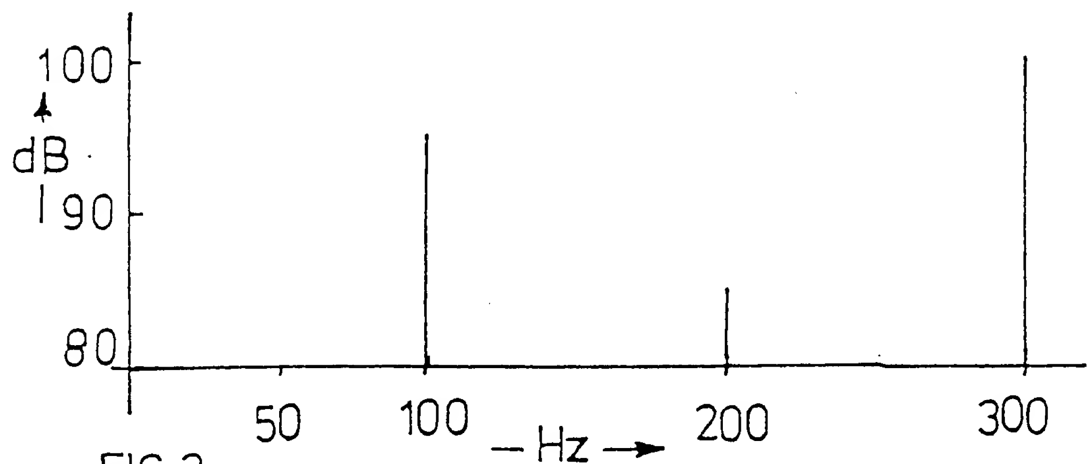

FIG. 2

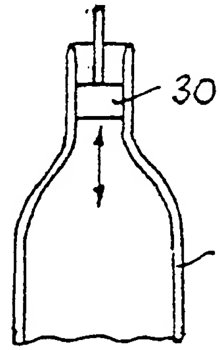

FIG. 5a

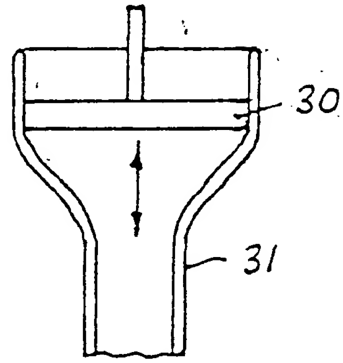

FIG. 5b

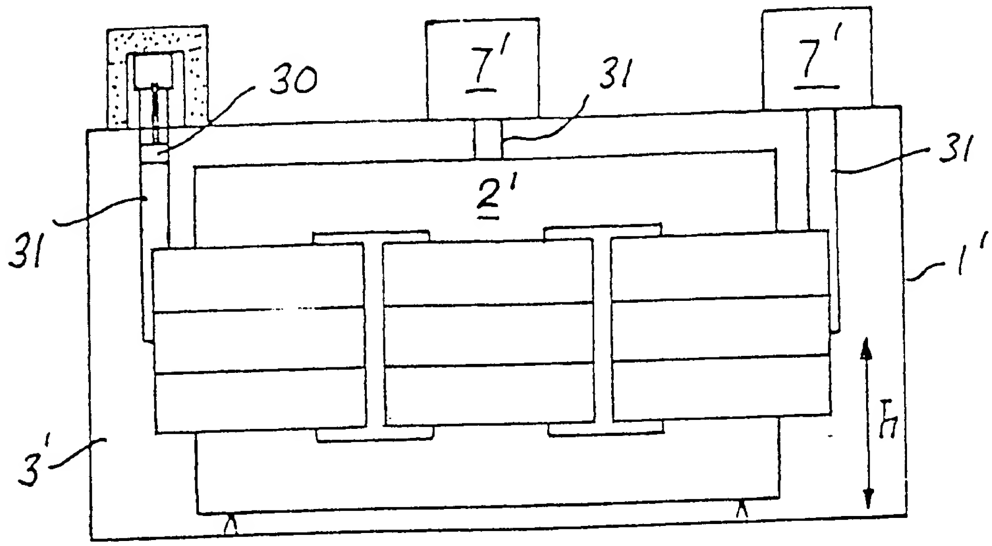

FIG.4

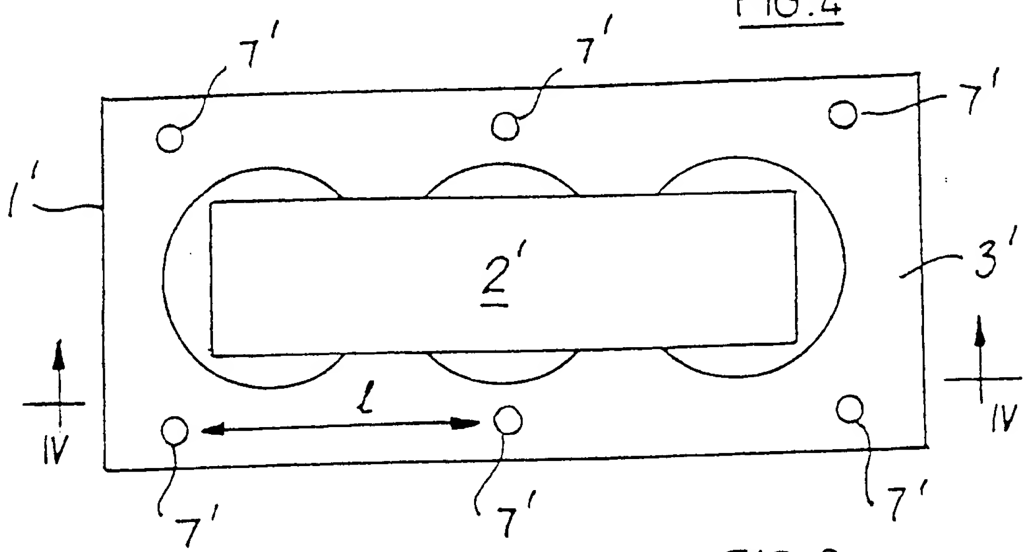

FIG.3

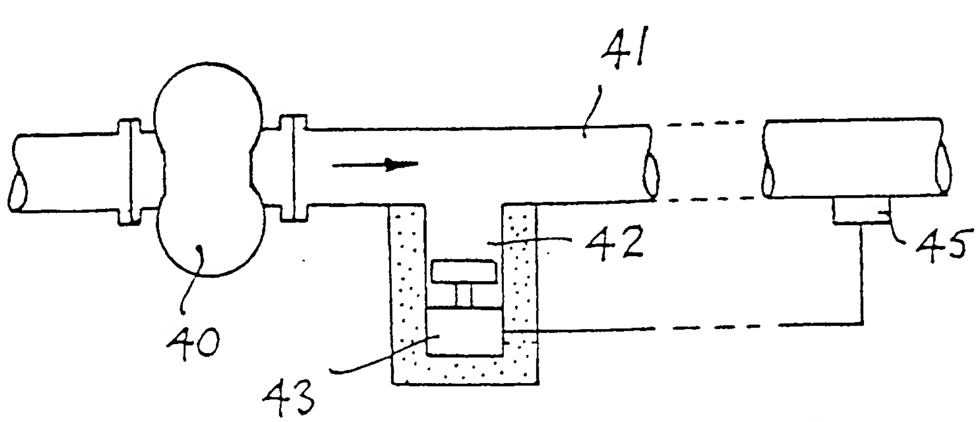

FIG.7

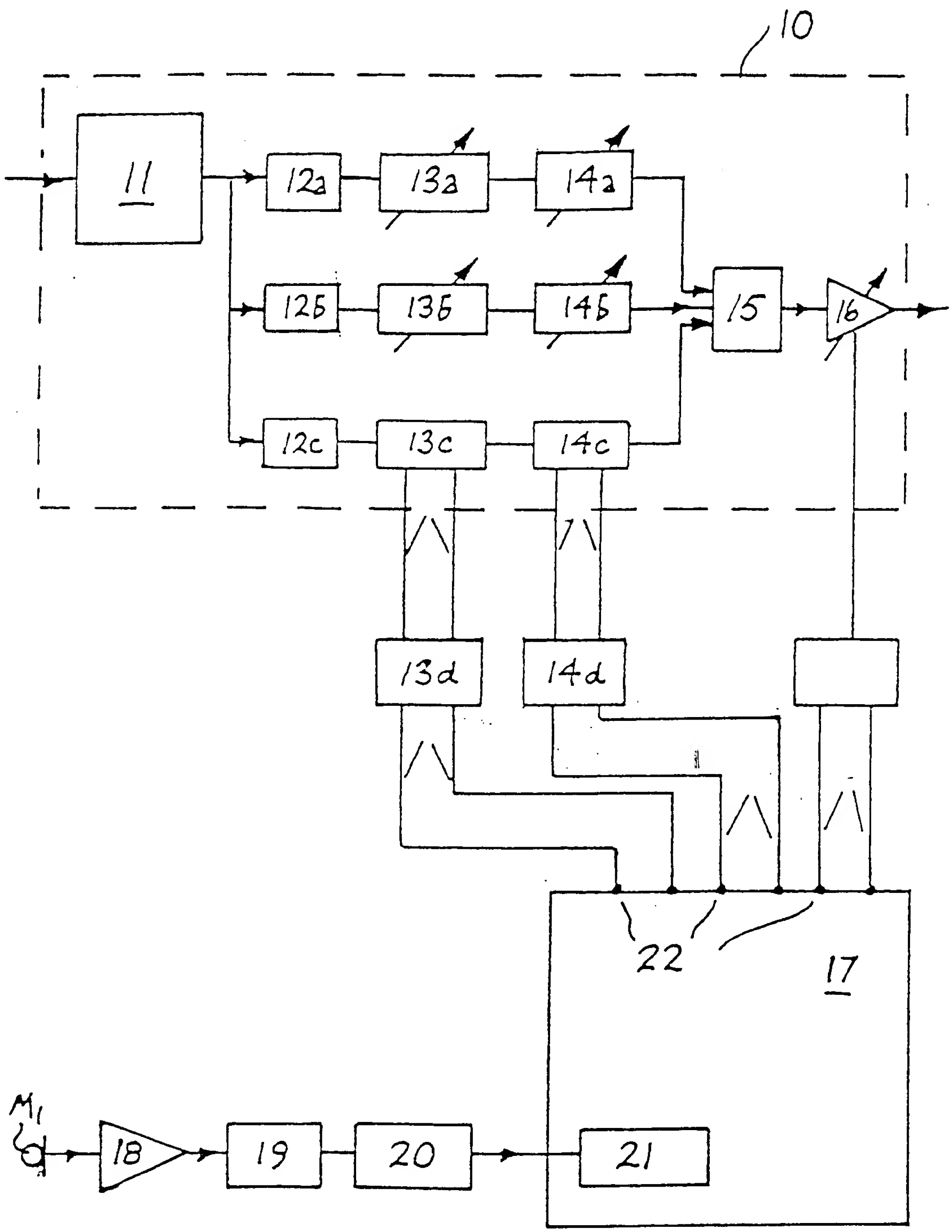
10
11
12a
13a
14a
12b
13b
14b
15
16
12c
13c
14c
13d
14d
22
17
M1
18
19
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FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 80/00194

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl.^{3}: G 10 K 11/16; H 01 F 27/33

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
Int.Cl.^{3}	G 10 K 11/16; H 01 F 27/33; H 02 K 5/24

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	GB, A, 897859, published May 30, 1962, see page 1, lines 9-19, 65-81, page 2, lines 14-54, page 2, line 100 - page 3, line 5, Ass. Electrical Ind. Ltd.	1-10
	GB, A, 782794, published September 11, 1957, see page 1, lines 69-88, page 2, line 51 - page 3, line 2, page 4, lines 31-35, page 6, lines 47-70, General Electric Cy.	3,4,9,10
A	GB, A, 1357330, published June 19, 1974, see page 1, lines 25-48, figures 1,2, The Secretary of State	1

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"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
February 2, 1981	February 9, 1981
International Searching Authority [1] EUROPEAN PATENT OFFICE Branch at The Hague P.O.Box 5818 Patentlaan ,2 2280 HV RIJSWIJK (ZH) The Netherlands	Signature of Authorized Officer [20] G.L.M. KRUYDENBERG

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